References and Notes

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Low Deuterium Content of Lake Vanda, Antarctica

Abstract. *Lake Vanda in Victoria Land, Antarctica, is permanently ice-covered and permanently stratified, with warm, salty water near the bottom. Deuterium analyses of lake water from several levels indicate that the lake has a low deuterium content, and that it is stratified with respect to this isotope. This low deuterium content supports the evidence from the lake's ionic content that the saline layer is not of marine origin, and it indicates that evaporation from the ice surface has taken place. The stratification of the lake with respect to deuterium suggests that the upper and lower layers of water were formed at different times from different sources of glacial melt water.*

Lake Vanda, a permanently ice-covered lake lying in ice-free Wright Valley in Victoria Land, Antarctica (Fig. 1), has exceptionally high water temperatures near the bottom but is permanently stratified, due to the high salt concentration of this warm bottom water. Deuterium analyses of the water indicate that the lake has quite a low deuterium content and that it is stratified with respect to this isotope. Its low deuterium content supports the evidence from the ionic composition that the saline layer is not derived from sea water but results from the evaporation of glacial melt water from the ice surface of the lake. It is postulated that the lower, more saline layers, which are depleted in deuterium relative to the upper layers, formed at an earlier time than the immediate past, and from a different source of glacial melt water than the upper layers.

Within the lake there are four separate layers of isothermal, isohaline water, at depths of 6 to 9 m, 18 to 37 m, 41 to 42 m, and 62 to 63 m, in which convective circulations are undoubtedly occurring (Fig. 2). The water balance of the lake represents primarily the difference between inflow of glacial melt water and evaporation from the ice surface. The valley is extremely arid, and any snow which falls evaporates directly to the atmosphere and does not enter the lake as melt water. These matters and an analysis of the heat balance of the lake during the antarctic summer are discussed in detail elsewhere (*1*). The chemical composition of the water of Lake Vanda and Lake Bonney, another ice-covered lake in an adjacent valley, has been discussed by Angino and Armitage (*2*). The concentrations of the most abundant ions in the near-bottom water of these two lakes are given in Table 1.

The results of the deuterium analyses are given in Table 2 and are compared with the distribution of temperature and dissolved salts (expressed as conductance) in Fig. 2. The very low concentrations of deuterium (*3*) found in Lake Vanda indicate that the lake water has come from melting glacial ice and is not marine in origin, for the lowest δ for antarctic sea water is -0.1, compared with -27.3 to -29.0 for Lake Vanda. Furthermore, evaporation from the lake could only have increased these values. The stratification of deuterium raises several questions which may bear on the hydrologic history of the lake.

Representative values of deuterium concentrations for antarctic snow are given in Table 2. As might be expected from the discussion given by Friedman *et al.* (*4*), the deuterium concentration in antarctic snow tends to be smaller with increasing altitude and distance from the coast. That these findings are of significance to the present argument is clear when the geographical situation and inferred history of Lake Vanda are taken into account. Lake Vanda

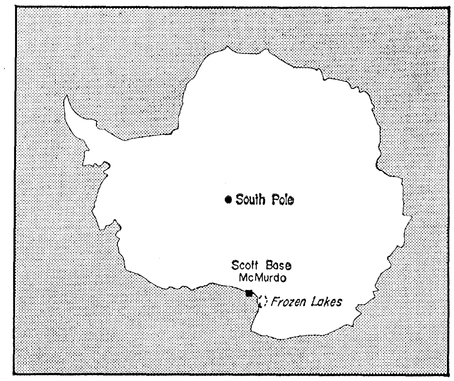

Fig. 1. Antarctica, showing location of frozen lakes in Victoria Land. Greenwich meridian is toward top of map.

lies at the lowest part of Wright Valley. This dry valley is blocked by glaciers at both ends; 26 km east of the lake the valley is blocked by the Lower Wright Glacier, a piedmont glacier which is not connected to the main antarctic ice sheet; to the west the valley ends at the Upper Wright Glacier, 17 km from the lake. This glacier flows directly from the main ice sheet. At present Lake Vanda is fed only by the Onyx River, a stream of melt water from the Lower Wright Glacier which flows only during the summer months. An old stream bed between the lake and the Upper Wright Glacier indicates that melt water flowed from this source at some time in the past. A series of well-preserved terraces indicates that the level of Lake Vanda was once at least 50 m higher than it is now.

The lowest concentration of deuterium in the lake occurs at 60 m ($\delta =$

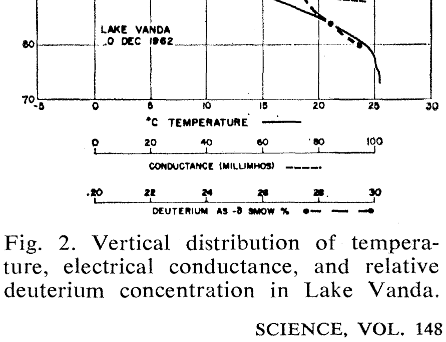

Fig. 2. Vertical distribution of temperature, electrical conductance, and relative deuterium concentration in Lake Vanda.

−29.4). In view of the lake's strong stratification, due to the high salt concentration at depth, it is probable that the deeper water has not been in contact with the atmosphere (or the lower surface of the ice) for a long time. On the basis of these considerations we suggest that the low concentrations of deuterium in the deeper water of Lake Vanda are attributable to a mixture of inflow of melt water from both the Upper and the Lower Wright glaciers. Since the Upper Wright Glacier originates from the snow on the higher antarctic plateau, above 2200 m, its deuterium content would be expected to be near the values reported for snow on Victoria Land [the mean δ value for three samples of snow taken about 300 km west and southwest of Wright Valley is −34.3 (*5*)].

The deuterium concentration of the upper layers of the lake (δ = −27.5 ± 1) suggests a different source of water. The deuterium content of the Lower Wright Glacier would be expected to be higher than that of the Upper Wright Glacier, due to its lower elevation (800 m) and its proximity to the Ross Sea. The δ value of −25.9 for the Onyx River is probably representative of this ice mass. Friedman and Redfield (*6*) reported that ice freezing at 0°C contains 2 ± 0.4 percent more deuterium than the water from which it froze. This effect would account for the 1.4-percent lower content of deuterium in the upper water of Lake Vanda than in the inflow water. The nearest coastal station for which deuterium data are available is Scott Station, about 60 km southwest, where the value for snow is reported by Lorius (*5*) to be −23.7.

It is suggested that Lake Vanda originally received water from both glaciers and that, by continued evaporation, the salt concentration was raised to the values now observed in the deep water. Then, either the Upper Wright Glacier retreated, so that melt water no longer reached the lake, or else the climate cooled, so that melting was reduced below that necessary to produce a flowing stream, thus eliminating this source of water. Because of its lower altitude and nearness to the marine influence of the Ross Sea, the Lower Wright Glacier continued to melt fast enough to provide an inlet for the lake, but this water did not mix with the saltier water already in the lake. However, since the lower glacier probably had a higher deuterium content than the lake water, the lake would have a decreasing deuterium concentration with depth, as observed (Table 2). A hydrologic history of the lake somewhat similar to this but postulating cessation of flow from the Lower Wright Glacier has been suggested by Wilson (*7*).

The maintenance of the deuterium content unchanged, which to our knowledge has not been previously suggested, could occur only in a permanently frozen lake. If evaporation occurred from the water surface, deuterium would be concentrated in the lake. However, sublimation from an ice surface does not concentrate deuterium in this manner, because of the structure of ice, which prevents the deuterium from entering into an equilibrium state with the water vapor in the atmosphere, as it does in the case of a liquid water surface. Sublimation does not produce fractionation of the D_2O and H_2O molecules, since the process is a sort of layer-by-layer removal of matter, with little or no molecular diffusion occurring between the subliming surface and the body of the ice. Therefore, once deuterium has entered the ice-covered lake its concentration can be changed only by mixing or advective processes.

Two conclusions can be drawn: (i) the water of Lake Vanda is clearly not of marine origin; (ii) the stratification of deuterium in the lake itself represents a historical record of the climatic changes affecting the sources of melt water entering the lake.

Several interesting questions arise from this preliminary discussion. With regard to the present problem, determination of the deuterium content of some ice samples from ice cover of Lake Vanda and from the Upper and Lower Wright glaciers is desirable. Moreover, information on the deuterium content of the water and ice cover of Lake Bonney, which is suspected on the basis of its chemical composition (*2*) to be partly of marine origin, would be very useful in pursuing this question.

Table 1. Partial composition of deep waters of lakes Vanda and Bonney. [From Angino and Armitage (*2*)]

Ion	Concentration (ppm): Sea water (Cl, 19 ‰)	Vanda (at depth of 66 m)	Bonney (at depth of 31 m)
Na^+	10,556	6,761	43,333
K^+	380	766	3,000
Ca^+	400	24,254	1,109
Cl^-	18,980	75,869	143,333
SO_4^{--}	2,649	770	525
HCO_3^-	140	126	378

Table 2. Results of deuterium analyses of snow and lake water from various regions of Antarctica.

Altitude (m)	Depth (m)	Concentration (ppm)	Percentage difference*
		Scott Station†	
16		123.4	−23.7
		Victoria Land†	
2276		106.6	−34.1
2437		106.9	−33.9
2479		105.5	−34.8
		South Pole‡	
2800		101.0	−37.5
		South Pole†	
2800		98.8	−38.9
		Lake Vanda	
123§	4		−27.3
123	9		−27.3
123	12		−26.5
123	20		−27.6
123	34		−27.6
123	39		−29.0
123	45		−28.4
123	50		−27.7
123	55		−28.2
123	60		−29.4
		Onyx River (inlet)	
		0	−25.9

* δ SMOW (*3*). † Lorius (*5*); δ SMOW values based on SMOW = 161.7; samples from Victoria Land are S-500, S-504, S-507. ‡ U.S.S.R. value [from Lorius (*5*)]. § Altitude of lake surface.

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